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Three-Dimensional Rotational Angiography as Guidance for Percutaneous Patent Ductus Arteriosus (PDA) Device Closure: A Case Report

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Abstract: Background: Patent Ductus Arteriosus (PDA) is a prevalent congenital heart defect characterized by the persistence of an open arterial connection between the aorta and the pulmonary. Percutaneous PDA closure involves deploying occlusion devices through catheter-based procedures. Case Presentation: We report a 1-year and 6-month-old girl diagnosed with Patent Ductus Arteriosus, presented with persistent complaints of failed to thrive , shortness of breath and recurrent cough. Physical examination revealed a continuous murmur at the upper left sternal border, and the Echocardiography examination confirmed a PDA with size of 4-7 mm, with diastolic shortening and dilatation of the Main Pulmonary Artery (MPA). The successful percutaneous PDA device closure procedure was performed using Three-Dimensional Rotational Angiography (3DRA), following an attempt with Two-Dimensional Angiography, which failed to determine the actual defect size in the patient. Conclusions: Confirming the morphology and size of a PDA can be difficult due to its location between the aorta and pulmonary blood vessels, making it a challenging congenital anomaly to assess accurately. 3DRA precisely delineates the PDA structure located between the aortic and pulmonary blood vessels and acts as a guidance tool for percutaneous PDA device closure.

Keywords: *Three-Dimensional Rotational Angiography, Patent Ductus Arteriosus, Pulmonary Hypertension, Percutaneous Device Closure.*

I. INTRODUCTION

The ductus arteriosus is a central vascular shunt connecting the pulmonary artery to the aorta,[1] Patent ductus arteriosus (PDA) is one of the most common congenital heart defects, accounting for 5%-10% of all congenital heart disease in term infants. The occurrence of PDA is inversely related to gestational age and weight, with an even greater incidence in preterm infants. PDA in term infants is usually associated with a functional defect, whereas in preterm infants it is associated with immaturity. Clinical signs of ductal patency include murmur, tachycardia, and congestive heart failure and associated symptoms.[2]

Therapeutic catheterization is currently the treatment of choice at most centers for most children and adults with patent ductus. Angiography defines the anatomy of the ductus arteriosus. Detailed assessment of the ductal anatomy is essential before transcatheter closure so that the proper device and device size can be chosen for the intervention. Important features include the minimum diameter, the largest diameter (usually at the aortic ampulla), the length, and the relationship of the ductus to the anterior border of the tracheal shadow, which helps guide device positioning.[3]

Traditionally, two-dimensional conventional angiography (CA) is the method used to visualize and percutaneously treat congenital heart diseases (CHD). While three-dimensional rotational angiography (3DRA) was already a well- established technique in neurology.[4] Out of 29 eligible scientific articles, it is evident that 3DRA offers detailed information about both the vasculature and surrounding tissues. It can be conducted quickly and safely. Additionally, it enhances interventions by serving as a guide and addresses limitations observed in CA (e.g., unlimited angulations).[5]

II. CASE PRESENTATION

A girl aged 1 year and 6 months presented with ongoing complaints of shortness of breath, recurrent cough, and failure to thrive. These issues have persisted since the patient was 4 months old. The patient is the fourth child among four siblings, born in a hospital with medical assistance. The patient's history includes being born prematurely, weighing 1,800 grams at birth. The mother had an uncomplicated pregnancy, but there is a notable family history of heart disease, specifically congenital heart disease (CHD). One of the patient's siblings is currently undergoing pharmacological treatment for a diagnosed patent ductus arteriosus (PDA), shedding light on a potential genetic predisposition. The physical examination identified a continuous murmur at the upper left sternal border. The weight is 8.000 grams, and the height is 74 centimetres.

The Chest X-ray examination indicates cardiomegaly with a cardio-thoracic ratio measurement of 0.55 cm. A prominently visible conus pulmonalis with heterogeneous consolidation in both lung fields suggests a condition of pulmonary hypertension (**Figure 1**).

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The Transthoracic Echocardiography examination has confirmed the presence of a 5 mm PDA. Continuous Wave (CW) Doppler on the PDA indicates a continuous flow pattern with a systolic gradient of 55 mmHg and diastolic gradient of 6 mmHg. This condition is associated with diastolic shortening and dilation of the Main Pulmonary Artery (MPA), measured at a diameter of 15 mm, suggesting the presence of Pulmonary Hypertension (**Figure 2**). Additionally, the echocardiogram identified an atrial septal aneurysm, mild Aortic Regurgitation (AR), mild Mitral Regurgitation (MR), and mild Tricuspid Regurgitation (TR). There's also dilation observed in the Left atrium (LA) and Left ventricle (LV). Both the systolic functions of the left and right ventricles are within normal limits.

The right heart catheterization (RHC) procedure was performed with the aim of closing the PDA. In the initial procedure, conventional angiography was used, capturing an Aortography with RAO 20º and LAO 90º positions, utilizing 15 ml of contrast volume, a flow rate of 10 ml/sec, and a pressure limit of 600 psi, revealing a 9 mm left to right PDA shunt (**Figure 3**). Pressure and saturation examinations of the Aorta Descendens (AoD) and Pulmonary Artery (PA) indicated AoD pressures of 65/30 (42) mmHg, AoD saturation of 99%, PA pressures of 42/35 (37) mmHg, and PA saturation of 84%. Subsequently, closure of the defect was decided using a Lifetech PDA Occluder device sized 16-18 mm, utilizing the retrograde technique, pulling the device towards the PA through the PDA, covering the Ampulla, and then expanding the PA disc. Physical examination, echocardiography, and Angiography were conducted to ensure proper device positioning. Aortic Coarctation (CoA) induced by the device was observed (**Figure 4**), prompting a downsizing to the Lifetech PDA Occluder device size 12-14 mm. However, during preparation of the device, Supraventricular Tachycardia (SVT) occurred, which eventually reverted to sinus rhythm after Cardioversion with 1 Joule/ KgBB energy, leading to the procedure being postponed for patient stabilization.

The patient underwent a second intervention procedure aimed at closing the PDA. This intervention began with pressure measurements in the AoD 84/56 (71) mmHg, Right Atrium (RA) 17/15 (13) mmHg, and PA 42/23 (34) mmHg. Aortography utilizing Three-Dimensional Rotational Angiography (3DRA) revealed a PDA shunt size of 4.2 – 4.3 mm (**Figure 5**), leading to the decision to close the defect using the Lifetech PDA Occluder size 10-12 mm employing the antegrade technique. The device was inserted into the Aorta through the PDA, and after the disc was expanded, evaluations including physical examination, echocardiography, and Aortography using Angiography at RAO 20º and True lateral positions with 15 ml of contrast, a flow rate of 10 ml/sec, and a pressure limit of 500 psi were conducted. The device appeared well-positioned, and no residual shunt was observed (**Figure 6**). Post-closure evaluation of the patient's vital signs showed normal results, and follow-up after 1 month showed clinical symptom improvement.

III. DISCUSSION

In the case above, the diagnosis of patent ductus arteriosus (PDA) is based on the patient's medical history from prenatal to current condition, physical examination, and diagnostic tests. The ductus arteriosus (DA) is a vital blood vessel that connects the pulmonary and systemic circulations in the fetus. Closure of the DA mostly occurs within the first three days of life in healthy full-term newborns. Low oxygen pressure and non-functioning pulmonary vasculature during fetal life, combined with circulating prostaglandin levels from the placenta, result in the ductus remaining open.[7]

Based on the patient's history, a 1-year 6-month-old girl presents with complaints of dyspnea, recurrent cough, and failure to thrive, which have been ongoing since the age of 4 months. This condition is consistent with congenital heart disease (CHD) manifestations including PDA, where dyspnea results from the imbalance between oxygen demand and supply, ultimately leading to chronic hypoxia. Children with CHD have an increased risk of morbidity due to lower respiratory tract infections, exacerbating the already compromised respiratory status and leading to recurrent infections.[9] The failure to thrive in PDA patients may be attributed to several contributing factors including inadequate calorie intake, decreased appetite, malnutrition due to hypoxia, venous congestion-induced malabsorption, increased energy expenditure, relative hypoxia, increased oxygen requirements, endocrine adaptation, and recurrent respiratory infections.[8]

The prevalence of Patent Ductus Arteriosus (PDA) is about 6-11% of all congenital anomalies. It is estimated that PDA occurs in about 1 in 2500–5000 live births, with approximately 4000 babies born with PDA in Indonesia each year. The incidence of PDA is higher in premature infants, around 8 per 1000 babies.[10]

In the case described, the patient was born prematurely with a birth weight of 1800 grams, placing them at risk for PDA. Recent research reports indicate that >50% of infants born at gestational age <26 weeks have an open ductus after 2 months post-birth.[11] Infants born weighing less than 1000 grams are at the highest risk for PDA. In this population, 70% will develop PDA by day 7.[7]

The patient's mother did not experience any complications during her pregnancy, however, one of the patient's siblings is currently undergoing pharmacological treatment for PDA diagnosis. PDA is associated with complex and multifactorial genetic causes. The majority of non syndromic PDA cases are caused by multifactorial genetics, where underlying genetic predisposition and environmental triggers during vulnerable periods likely contribute significantly to the condition.[11]

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Physical examination reveals a continuous murmur at the upper left edge of the chest bone, consistent with the classic sign of a PDA murmur, known as a "machinery" murmur, which is continuously audible below the clavicle, radiating to the back, although it may also manifest as a systolic or holosystolic murmur.[7] There is no cyanosis, clubbing of fingers, or rales and wheezing detected on lung auscultation. PDA falls under acyanotic congenital heart defects (CHD), which typically involve lesions with a left-to-right shunt characterized by oxygenated blood entering the deoxygenated circuit through the tissues. Thus, the clinical manifestations are consistent with this case. The left-to-right shunt results in excess volume in the space where the blood is being diverted.[12]

The chest X-ray of the patient reveals cardiomegaly (increased cardiothoracic ratio) and increased pulmonary markings often seen in chest radiographs of PDA patients. A clearer picture of the DA is obtained through echocardiography, which is the gold standard for diagnosis. Echocardiography will demonstrate the size of the opening, indicate the shunt, and allow estimation of the average pulmonary artery pressure. The information obtained from echocardiography is crucial for accurate diagnosis.[2]

We conducted a Transthoracic Echocardiography (TTE) examination to confirm the presence of a 5 mm PDA. TTE is the gold standard for evaluating PDA. Therefore, TTE can be used to determine the device for PDA closure and also during the procedure. Percutaneous PDA closure is the preferred procedure for definitive ductal closure in adults, children, and infants weighing ≥6 kg. [13]

Continuous Wave (CW) Doppler on PDA reveals a continuous flow pattern with a systolic gradient of 55 mmHg and a diastolic gradient of 6 mmHg. This condition is associated with diastolic shortening and widening of the Main Pulmonary Artery (MPA) measured at a diameter of 15 mm, indicating the presence of Pulmonary Hypertension (Figure 2). We decided to perform Right Heart Catheterization (RHC) with the aim of closing the PDA. RHC is usually performed by accessing the common femoral vein in the groin, internal jugular vein in the neck, or antecubital vein in the arm.[15]

During the initial procedure, we utilized conventional angiography (CA), capturing Aortography with RAO 20° and LAO 90° positions, using a contrast volume of 15 ml, flow rate of 10 ml/second, and pressure limit of 600 psi, revealing a residual 9 mm shunt to the right PDA (Figure 3). CA is a method still routinely used to visualize and treat congenital heart diseases (CHD) percutaneously, although three-dimensional rotational angiography (3DRA) has become a frequently utilized technique in the field of neurology. It wasn't until 2001 that Boccalandro and colleagues reported the first application of 3DRA in adult patients with congenital heart disease.[5]

The selection of device size was based on the measurement of the PDA isthmus diameter during the echocardiographic assessment. The chosen device options include Amplatzer Duct Occluder I (AGA), Konar Multifunction VSD Occluder (LifeTech), or PDA Occluder Device (MemoPart) if the PDA is moderately large. We decided to use the Lifetech PDA Occluder device sized 16-18 mm. This device can be used retrograde or antegrade in certain situations where the PDA size is large but still amenable to retrograde closure. The retrograde approach offers a shorter procedural time compared to the antegrade approach, where the catheter requires more manipulation to be directed into the right ventricle and PA to reach the PDA.[13] Using the retrograde technique, the device is pulled towards the pulmonary artery (PA) through the PDA. Physical examination, echocardiography, and angiography were performed to ensure the correct position of the device. Aortic coarctation (CoA) induced by the device was observed (Figure 4), prompting a reduction in the size of the Lifetech PDA Occluder device to 12-14 mm.

Based on pre-catheterization data from a study, Transthoracic Echocardiography (TTE) or Transesophageal Echocardiography (TEE) show similarity in assessing lesion size. An addition of 2 - 4 mm from the smallest PDA diameter is made in device selection, but the device size will double the PDA size if accompanied by pulmonary hypertension. The choice of device type and size is best tailored based on the size (minimal ductal diameter) and possible shape of the ductus. Although considered safe, there is a potential for complications associated with percutaneous transcatheter closure procedures, such as device embolization, residual shunt, left pulmonary artery obstruction, development of aortic coarctation, and vascular injury. During follow-up, we noted significant progression of aortic coarctation. Considering the significant protrusion of the device component into the aortic lumen, we may conclude that the large device is responsible for the development of coarctation in this case,[14] Subsequently, supraventricular tachycardia (SVT) occurred, which eventually reverted to sinus rhythm after cardioversion with 1 Joule/kg body weight, leading to the postponement of the procedure for patient stabilization.

After the patient stabilized, we proceeded with the second intervention procedure aimed at closing the PDA. Three-Dimensional Rotational Angiography (3DRA) was used for aortography, as during the initial procedure with CA, it was challenging to identify the defect size and determine device size. The 3DRA results showed a PDA shunt size ranging from 4.2 to 7.9 mm (Figure 5), leading to the decision to close the defect using a Lifetech PDA Occluder sized 10-12 mm with the antegrade technique. The second intervention was successful, with the device appearing to be in a good position, and no residual shunt was observed (Figure 6). Evaluation of the patient's vital signs post-closure indicated normal results, and follow-up after 1 month showed improvement in clinical symptoms.

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The clinical implementation of three-dimensional (3D) imaging demonstrates significant advancements in the diagnosis and management of congenital heart defects by providing visualization of spatial anatomical relationships, enhancing understanding of the complex structural relationships seen in congenital heart defects. This modality has proven effective in preoperative planning through procedural integration. Three-Dimensional Rotational Angiography (3DRA) is a novel imaging technology acquired during cardiac catheterization that enables the rapid acquisition of high-resolution volumetric data sets through the rotation of a flat-panel detector mounted on a C-arm, similar to computed tomography (CT).[16]

Congenital heart defects in children, especially complex ones, pose challenges in imaging due to the complexity and variability of structural relationships. Conventional 2D angiography is limited by vessel overlap and foreshortening besides lacking depth information. These limitations are addressed by the representation of the heart's 3D structure, and thus, multimodality 3D imaging and image fusion emerge as crucial additions to the congenital cardiac catheterization laboratory. The introduction of 3DRA has enabled the development of management paradigms involving 3D imaging solutions for pre-therapy assessment, treatment guidance, and post-treatment evaluation. 3DRA provides rapid image acquisition at high spatial resolution compared to multidetector-CT (MDCT) and MRI angiography, albeit with less contrast and radiation dose reported to be lower than MDCT for specific applications. From a safety perspective, side effects of 3D-RA have not been reported in the literature.[16]

The indications for PDA intervention are (1) to maintain patency in patients with congenital heart defects dependent on the ductus, and (2) to close the defect in symptomatic children with significant hemodynamic left-to-right shunting. In conditions like hybrid palliation for hypoplastic left heart syndrome, this modality has been used to aid in visualizing the morphology of the ductus and surrounding vessels for stent selection and placement. Three-dimensional 3DRA has the capability to depict the duct from various perspectives with a single acquisition. Additionally, visualization of the duct's origin and insertion point on the proximal pulmonary artery can identify occult stenosis, which can impact treatment decisions and guide procedures. In the context of PDA closure, several authors have reported the utility of 3D-RA in depicting duct orientation and morphology for device selection and implantation.[16]

Since its introduction into the field of cardiology in 2001, 3DRA has been increasingly utilized in both adult and pediatric CHD patients. This has optimized interventions as the images can serve as a guide for procedures, overcoming limitations seen in conventional angiography (such as unrestricted angles). Most articles depict the diagnostic quality of 3DRA as superior to conventional angiography. 3DRA visualizes complex anatomy in detail before surgical or catheter-based interventions, including surrounding tissue anatomy (e.g., airways), and has the ability to view anatomy from unlimited angles. Moreover, interventions are performed more quickly and safely, as the 3D images obtained serve as roadmaps for percutaneous intervention guidance. However, there are also concerns regarding 3DRA. For instance, higher radiation doses, especially in children. Some studies report higher radiation doses compared to CA and suggest that dose reduction measures should be implemented.[5]

A study was designed to establish radiation and contrast protocols for the use of 3DRA in pediatric cardiac catheterization laboratories to identify radiation doses and contrast levels suitable for children. Kang et al., (2019), recommended contrast doses ranging from 0.5 to 2 cc/kg, typically diluted with normal saline (50%-66% contrast). To compare the radiation dose required to obtain 3DRA using low-dose radiation protocols, it was adjusted to standard CA. Radiation exposure from the clinical application of 3DRA protocols in children has not been previously reported. The contrast volume administered was approximately 1.6 mL/kg diluted to 1:2 for children weighing 30 kg and 2:3 for children weighing >30 kg. The contrast volume was injected slowly over 5-6 seconds, which, along with RVP, prevented contrast from leaking out of the desired area during the rotation duration.[16]

The 3DRA modality in imaging has been widely used, not only in cardiac-related areas but also in several other fields in pediatric patients, such as vascular malformations, intracranial aneurysms, neoplasms, and trauma. Angiography with 3D rotation is useful in determining intracranial and extracranial vascular malformations. In children, these malformations are typically high-flow, with complex anatomy between supplying arteries and venous drainage. In the evaluation of intracranial aneurysms, 3DRA provides detailed information about the neck of the aneurysm, including diameter, morphology, and orientation of feeding arteries and surrounding vessels. These characteristics are essential for determining the type and size of the appropriate endovascular coils for embolization. In evaluating the vascular anatomy of intracranial neoplasms, 3DRA has been proven useful for preoperative surgical planning or preoperative embolization. The dataset from 3DRA allows accurate depiction of the vascular supply to the tumor, providing neurosurgical teams with an ideal surgical approach and reducing the risk of encountering unexpected vascular anatomy during surgery.[18]

Conventional angiography and 3DRA can be used as adjuncts for evaluating patients with trauma that may be difficult to identify with MDCT. Rotational angiography itself takes only a few seconds to acquire, with a time gap of only 180 seconds for 3D image reconstruction. In the post-trauma imaging evaluation, 3DRA is also useful in depicting incidental findings that are detected.[18]

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➢ *Evidence Attachment*

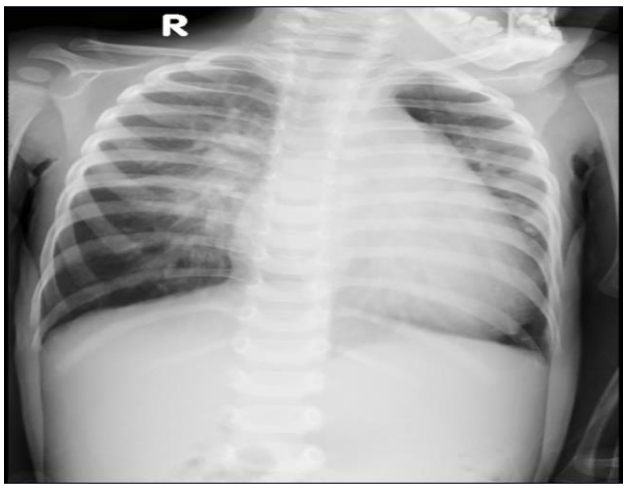

Fig 1. The Chest X-Ray Examination Indicates Cardiomegaly , A Prominently Visible Conus Pulmonalis with Heterogeneous Consolidation in Both Lung Fields Suggests A Condition of Pulmonary Hypertension.

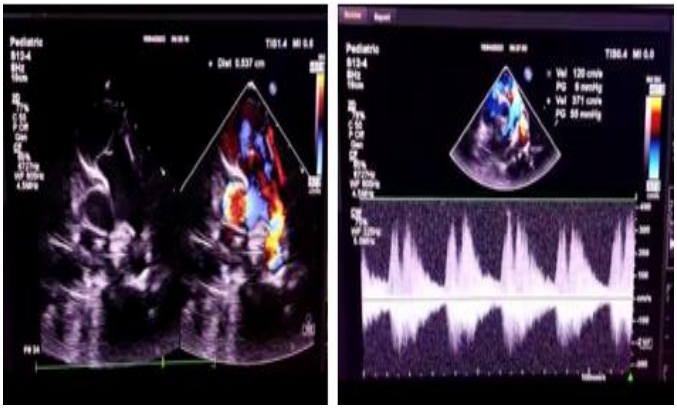

Fig 2. The Transthoracic Echocardiography (TTE) Examination Has Confirmed The Presence of A 5 Mm PDA. Continuous Wave (CW) Doppler on The PDA Indicates A Continuous Flow Pattern with A Systolic Gradient of 55 Mmhg and Diastolic Gradient of 6 Mmhg.

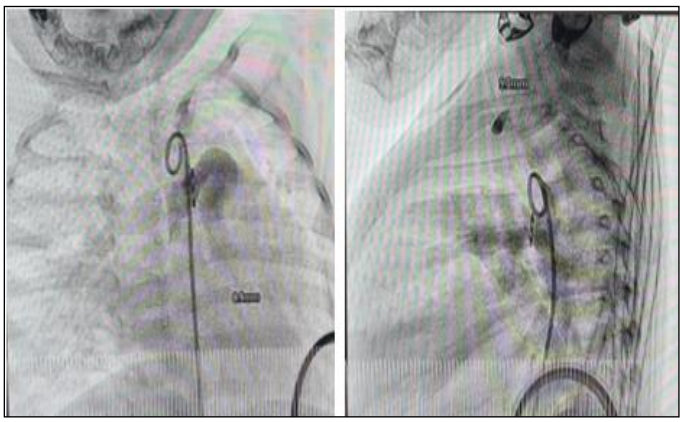

Fig 3. The Conventional Angiography Was Used, Capturing An Aortography With RAO 20º and LAO 90º Positions, Utilizing 15 Ml Of Contrast Volume, A Flow Rate of 10 Ml/Sec, and A Pressure Limit of 600 Psi, Revealing A 9 Mm Left To Right PDA Shunt.

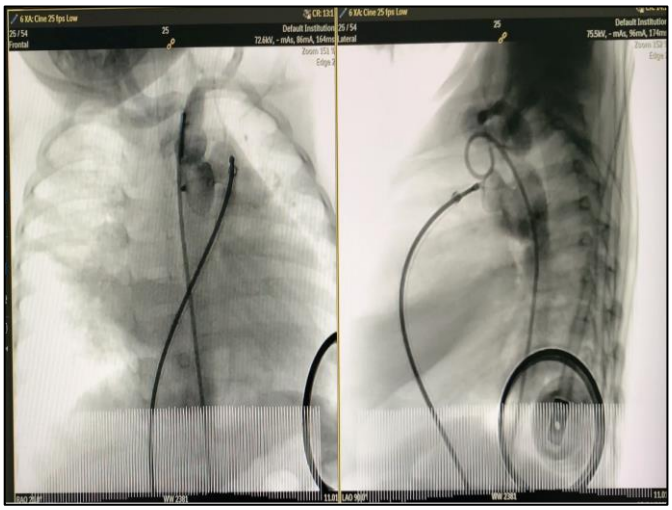

Fig 4. Closure of the Defect was Decided Using a Lifetech PDA Occluder Device Sized 16 -18 Mm, Utilizing The Retrograde Technique. Aortic Coarctation (Coa) Induced by the Device was Observed.

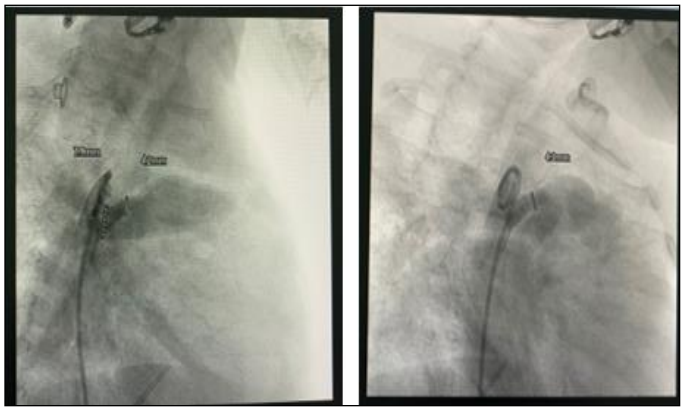

Fig 5. The Patient Underwent a Second Intervention Procedure Aimed at Closing the PDA. Aortography Utilizing Three-Dimensional Rotational Angiography (3DRA) Revealed A PDA Shunt Size of 4.2 - 4.3 Mm

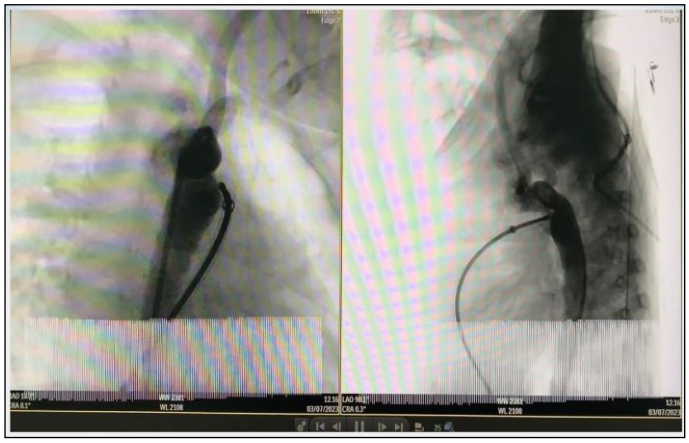

Fig 6. The Lifetech PDA Occluder Size 10-12 Mm Employing The Antegrade Technique. The Device Was Inserted Into The Aorta Through The PDA, And After The Disc Was Expanded, The Aortography Using Angiography At RAO 20o And True Lateral Positions Showed The Device Appeared Well-Positioned, And No Residual Shunt Was Observed

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IV. CONCLUSION

Confirming the morphology and size of a PDA can be difficult due to its location between the aorta and pulmonary blood vessels, making it a challenging congenital anomaly to assess accurately. This case shows that Three-Dimensional Rotational Angiography precisely delineates the PDA structure located between the aortic and pulmonary blood vessels and acts as a guidance tool for percutaneous PDA device closure.

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